A PROPOSAL CONCEPTUALIZATION OF A HYBRID BIO-MOTO-REDUCTOR ACTUATOR AND THE "VIRTUAL SHAFT" HYPOTHESIS

M.A.Venegas*

*Nano Science and Technology Institute affiliation.
**Texas Instruments de México, Sensors and Controls Division, Av. Aguascalientes Sur 401, Ex-Ejido Salto de Ojocaliente 20270, Aguascalientes, Ags. México, m-venegas1@ti.com
***Instituto Tecnológico de San Luis Potosí Campus Aguascalientes, Mechanical Engineering Department., Ags. México

ABSTRACT

Motors are one of the most used motion devices in so many places, with high impact in the industry; they provide rotary motions that generate useful work at almost any particular application. Most of the time, motors must need to be connected to the entire mechanical system through a transmission mechanism to give the optimal performance to the system, they tend do be generic Moto–Reductors or Speed-Increasers that can be used in certain applications in the macro world. This paper idealizes this concept at the nano world, with a different type of motor, a motor that has been created by Nature evolution and seems to be the tiniest motor known [16] with high efficiency performance [1][4], the F1-ATPase motor; and then, achieve some process or activity. We are conceptualizing a general idea for a prototype of a hybrid Bio-Moto-Reductor actuator using the F1-ATPase Motor Bio-Device as a main motion rotary producer. We also idealize the hypothesis of a new and novel concept for rotary motion transmissions, the “Virtual Shaft”.

Keywords: Motor Reductor, Speed Increaser, F1-ATPase motor, Transmission.

1 INTRODUCTION

Mechanical engineering has created a solid theoretical and practical knowledge in transmissions and Power Adaptation for coupling motors to an entire mechanical system [6]. A very common device used in the industry is the Motor – Reductor, which sometimes is based on a Worm – Crown Gear type Transmission gearbox. These type of Motor – Reductors drastically increase the torque at the final shaft, and at lower speed, they also can be accurate for a certain application. However sometimes our needs will require speed instead of torque at the final shaft, from where a transmission of the type Spur Gears or Helical Gears can satisfy these needs. On the Other hand, the great advances achieved in Molecular Biology, have enabled us to explore more in detail the mechanical – chemical phenomena occurred in the biology systems down to the nano and meso scales world[1][2][8][14][17]. They seem to be Mechanical-Chemical models that convert Chemical energy into Mechanical useful work. Nature evolution has created molecular machines with high efficiency performance that has been the main focus of many studies.

The great advances in nanofabrication Technology and Bio- Chemical interfacing methods, [2][3][4][16], now enable us to “weld” or assemble organic subsystems with inorganic structures. All this knowledge converges in an interesting and new field that will allow for next generations of Machines and devices, “The Hybrid – Machines” that will bring an infinity of new fields of research and practical applications.

2 A THREE PHASE BIO-MOTOR MODEL

According to the Walker Structure and the research and experimentation done by Oster & Wang and Kinosita’s Lab., the F1-ATPase motor sub-complex consists of three main subunits as minimal elements that work like a rotary and stator: α_3, β_3, and γ[1][4][7][10][11][12]. The rotation of the rotor, the γ subunit will be by done by the consecutives power strokes done at the βs subunits; when the ATP molecule binds to the Catalytic site near the βs subunits, producing a 30º bend on each β, and turning 120º the γ subunit rotor shaft at an acceptance concentration of ATP. There are several approaches that address the occupancy of the catalytic site in a uni-site or multi-site form. It is very important to conceptualize a three phase bio-motor device that can be controlled to turn in CW and CCW direction. Considering the switch-less F1 model proposed by Kinosita Jr.[4]. This paper proposes a three phase bio motor idea at first glance, figure 1.

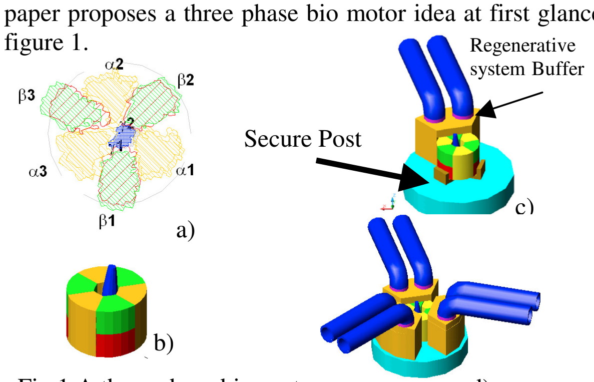

Fig.1 A three phase bio-motor conceptualization

In Figure 1, we conceptualize a three phase biomotor device, which has 3 Buffers filled with regenerative solution in order to avoid MgATP inhibition [14][18][19], and two input ports at every buffer from where the ATP nutrient is injected to each β subunit. Now we can think in a sequence of ATP injection as many authors have proposed [4], and depending on the sequence we may be able to turn either CW or CCW direction.

2 THE BIO-MOTO-REDUCTOR CONCEPTUALIZATION

The γ rotor shaft, has an asymmetric shape which turns in an asymmetric fashion, it is important to have a more concentric rotary motion before attaching it to the main shaft. An intermediate shaft, which consist of a conic Couple, a conic helical spring, the main base rotary assembly and a retainer, which helps to have either a concentric rotary motion but also to keep isolated the main cavity, filled with ultra clean water, and keeping the core structure protected from the environment is proposed. As shown in fig. 2

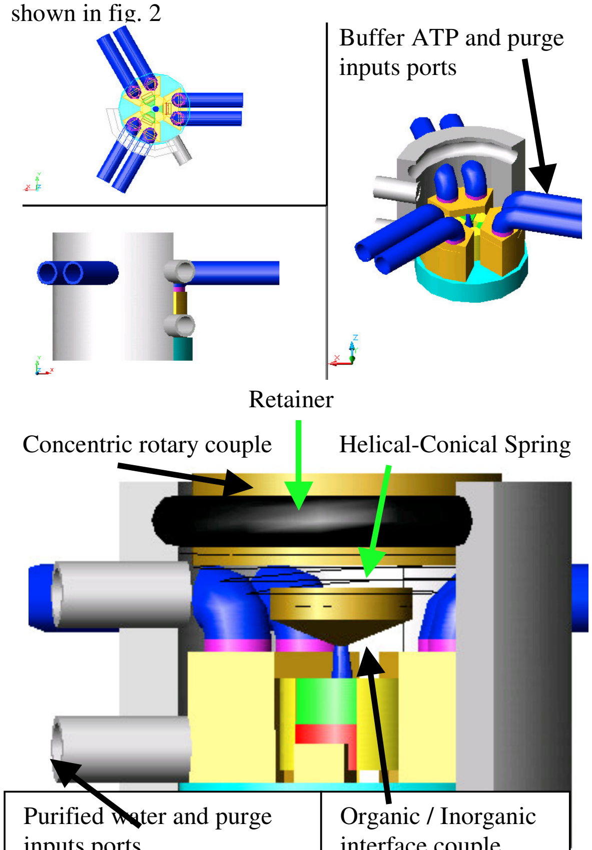

Fig. 2: A Concentric rotary Bio Actuator.

Having a concentric rotary motion at the main structure assembled to the main gear transmission, a Worm gear type, with a mechanical base at the end and keeping the concentricity of the entire system. Fig. 3

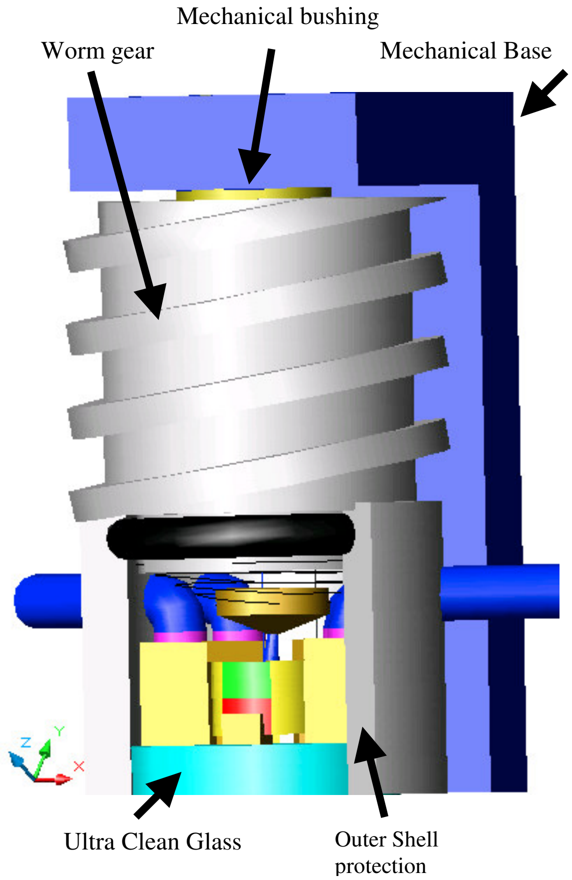

Fig. 3 The Worm gear assembly

These type of mechanical transmissions increase torque, but this conceptualization is restricted by so many factors, e.g. the total friction at the retainer and outer shell protection need to be lower than the permissible shear force of the γ rotor, but with a sufficient enclosure force to keep the core system hermetically assembled. Another important factor is the rigidity of the entire system, at this scale, matter seems to be soft, and a very mechanical rigid structure as well as a good assembly needs to be considered too. Other important parameters to be considered are: the Angular Speed, Angular displacement, torque and torsional moment at the γ rotor but also, this parameters differ at the main rotary concentric assembly, which will be the input of the Worm-Crown Shaft transmission and therefore, we must consider that this intermediate shaft, between the γ subunit and the Worm gear input will be affected by so many factors that will impact the rotary motion

The entire Bio-Moto-Reductor is shown in fig. 4.

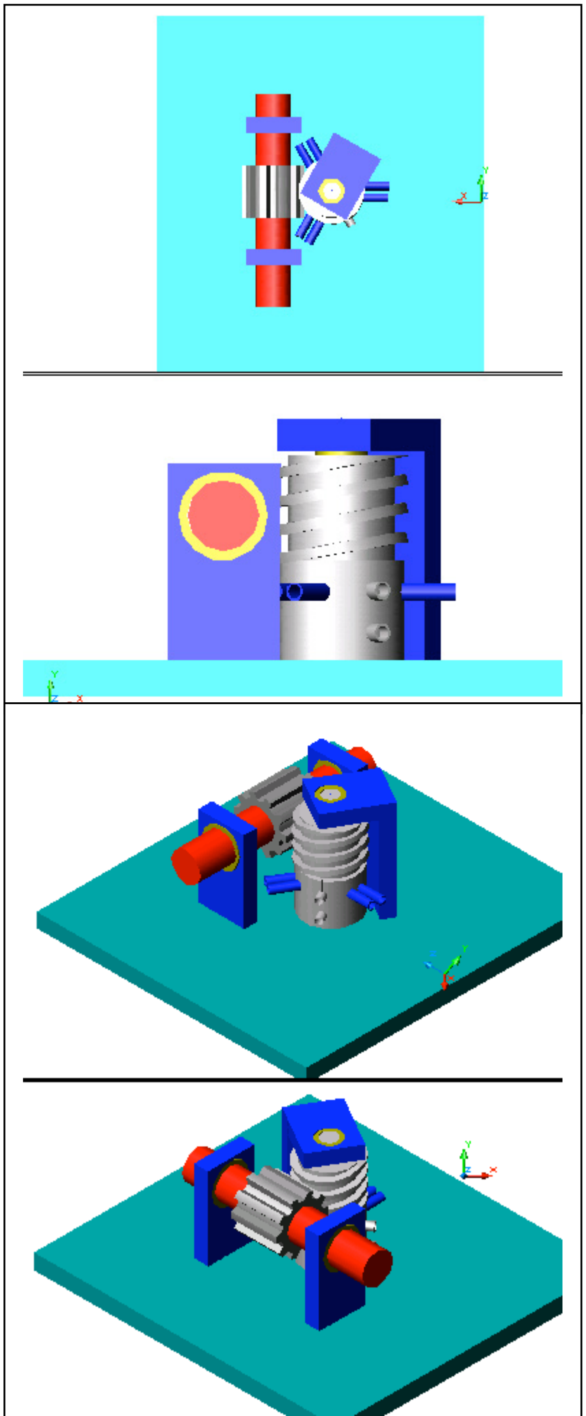

Fig. 4 The Hybrid Bio-Moto-Reductor Conceptualization.

The final shaft shown in figure 4 can also be connected to another type of reduction, we can also consider this shaft as input of a planetary gear box, and this will increase the torque.

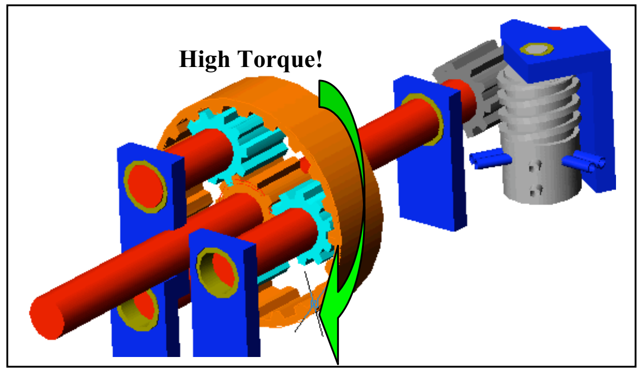

Fig. 5 A planetary Gear Box at the final shaft.

3 THE HYPOTHESIS OF THE VIRTUAL SHAFT

The mechanical – bio-chemical model shown above is totally coupled in the entire transmission this means that there going to be so many restrictions that must be considered for a more formal design. A very important factor in Worm type transmissions is when changing the direction, this type of transmission tend to present a worm tied, and this is a very important feature that must be considered.

There are several types of transmission couples some of them are: Mechanical shaft transmission, Electrical Transmissions, hydrodynamic transmissions, etc. they are connected through mechanical systems, flow fluidics, or electrically, and so many other forms.

The virtual shaft consists in the use of the Magnetic force to transmit motion of a Magnet, increase speed and / or torque. This can give us two benefits: to amplify the γ subunit motion (either to increase speed or torque) but also to isolate the protein motor from the entire mechanical system. Fig 6 shows a general over view.

NSTI-Nanotech 2004, www.nsti.org, ISBN 0-9728422-7-6 Vol. 1, 2004

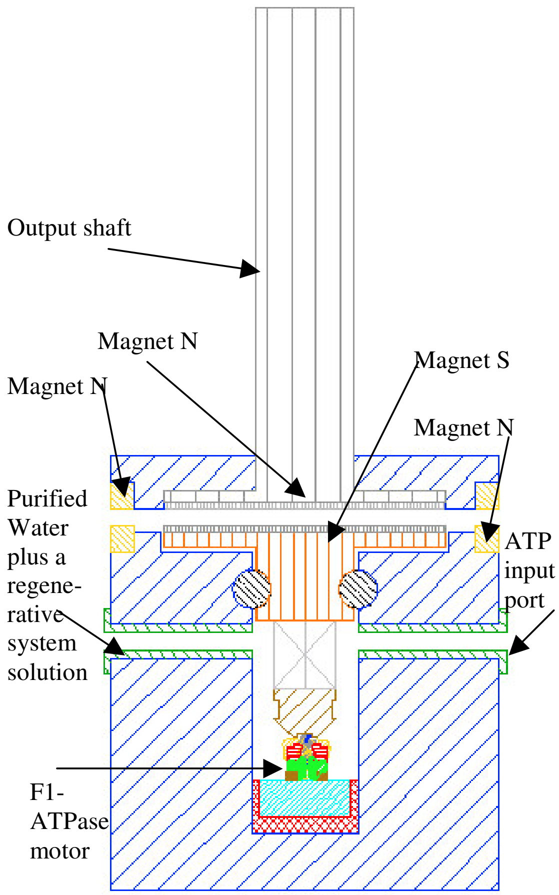

Fig. 6 the Virtual Shaft powered with the F1-ATPase motor sketch.

3 CONCLUSIONS

Only a general overview of the hypothesis is presented. This research is only at the beginning steps and conceptualization ideas. The systems presented above require a lot of analysis and calculations for a more formal design, many restrictions and considerations must be taken into account. The research is however already started and the journey is underway.

4 REFERENCES

[1] George Oster and Hongyun Wang, "Reverse engineering a protein: the Mechanochemistry of ATP synthase", Biochimica et Biophysica Acta 1458, 29, 2000.

[2] Carlo Montemagno and George Bachand "Constructing nanomechanical devices powered by biomolecular motors", Nanotechnology, 10, 7, 1999.

[3] Ricky K. Soong,1,2 George D. Bachand,1,2 Hercules P. Neves,1,2 Anatoli G. Olkhovets,1,3 Harold G. Craighead,1,3 Carlo D. Montemagno1,2* "Powering an Inorganic Nanodevice with a Biomolecular Motor", Science, Vol 290, 4, 2000.

[4] Kazuhiko Kinosita Jr, Ryohei Yasuda, Hiroyuki Noji and Kengo Adachi, "A rotary molecular motor that can work at near 100% efficiency", The Royal Society, 355, 17, 2000.

[5] Raymundo Fernández Moreno, "Diseño de Maquinas I y II", Universidad Autónoma de San Luis Potosí, Facultad de Ingeniería, Área de Ingeniería Mecánica Eléctrica, Vol. I, II, 192, 2002, 2003.

[6] Raymundo Fernández Moreno, "Transmisión y adecuación de potencia", Universidad Autónoma de San Luis Potosí, Facultad de Ingeniería, Área de Ingeniería Mecánica Eléctrica, Vol. I, 170, 2000.

[7] George Oster and Hongyun Wang, "How Protein Motors Convert Chemical Energy into Mechanical Work", 22 pages.

[8] Carlos Bustamante, David Keller, And George Oster "The Physics of Molecular Motors" ACC Chem. Res., 34, 8, 2001.

[9] Kazuhiko Kinosita, Jr. "Single-Molecule Physiology ", Center for Integrative Bioscience, Okazaki National Research Institutes
Higashiyama 5-1, Myodaiji, Okazaki 444-8585, Japan.

[10] Timothy Elston, Hongyun Wang & George Oster, "Energy transduction in ATP synthase", Nature, Vol. 391, 4, 1998.

[11] George Oster and Hongyun Wang, "Why is the mechanical efficiency of F1 ATPase so high? ", Departments of Molecular & Cellular Biology and ESPM, University of California, Berkeley, and School of Engineering, Dept. of Applied Mathematics & Statistics, University of California, Santa Cruz, California 95064, 26 pages, 2000.

[12] Kazuhiko Kinosita Jr., Ryohei Yasuda & Hiroyuki Noji "F1-ATPase: a highly efficient rotary ATP machine" Keio University, Essays in Biochemistry volume 35, 16, 2000.

[13]Carlo Montemagno, “Artificial Life and Nanobiotechnology; Foundations for Autonomous Robotic Systems ” Presentation of the Workshop on Revolutionary Aerospace Systems Concepts for Human/Robotic Exploration of the Solar System Langley, VA November 6-7, 2001.

[14] Tomoko Masaike, Eiro Muneyuki, Hiroyuki Noji, Kazuhiko Kinosita Jr.,and Masasuke Yoshida, “F1-ATPase Changes Its Conformations upon Phosphate Release” THE JOURNAL OF BIOLOGICAL CHEMISTRY, Vol. 277, 7, 2002.

[15] Kengo Adachi, Ryohei Yasuda, Hiroyuki Noji, Hiroyasu Itoh, Yoshie Harada, Masasuke Yoshida, and Kazuhiko Kinosita Jr., “Stepping rotation of F1-ATPase visualized through angle-resolved single-fluorophore imaging” Department of Physics, Faculty of Science, Kanazawa University, Japan, vol. 97, 5, 2000

[16] Hiroyuki Noji, Ryohei Yasuda, Masasuke Yoshida, and Kazuhiko Kinosita Jr, “Ni-NTA immobilization of F1-ATPase — the World’s mallest rotary motor, Qiagen News, 3, 3, 1998.

[17] George Oster and Hongyun Wang “ATP Synthase: two rotary molecular motors working together” University of California, Berkeley. Encyclopedia of Molecular Biology, Vol. 4, 19

[18] Yoko Hirono-Hara, Hiroyuki Noji, Masaya Nishiura, Eiro Muneyuki, Kiyotaka Y. Hara, Ryohei Yasuda, Kazuhiko Kinosita Jr., and Masasuke Yoshida, “Pause and rotation of F1-ATPase during catalysis”, PNAS, Vol. 98, 6, 2001

[19] Ryohei Yasuda, Hiroyuki Noji, Masasuke Yoshida, Kazuhiko Kinosita Jr. & Hiroyasu Itohß, “Resolution of distinct rotational substeps by submillisecond kinetic”, Nature, Vol. 410, 7, 2001.

[1] I would like to thank in a very special manner Dr. Christian Joachim, Head of the NanoScience Group CEMES/CNRS, Toulouse Cedex France; for his help, great contributions and orientation.

[2] Thanks to Dr. Masasuke Yoshida, Dr. Kazuhiko Kinosita Jr., Dr. Carlo Montemagno and Dr. George Oster for their permission to access the information used, product of their amazing and radically novel research in this extraordinary new field.

[3] **Alex Porter,** Texas Instruments SC Marketing, Thank you very much for spend some time in reading, reviewing and correcting this document.

[4] Thanks to Roberto Contreras Lizárraga, Head the Mechanization department at Texas Instruments de México, for his grate contribution and support.

[5] Thanks to John Birtwell, Head the Manufacturing Administration at TI S&C Division, for his help in the redaction of this document.

[6] Thanks to Dr. Sergio Rodríguez Quiñones and Dr. Raymundo Fernández Moreno, professors of the San Luis Potosí Technology Institute, Mechanical Department, for his valuable point of view and great orientation.

[7] Thanks to Engineer Carlos Javier Villagomez for his motivation and good advice.

[8] Thanks to Mr. Dennis Buss, SITD ADMIN of Texas Instruments, for sponsoring the Nanotech2004 congress and opening a new opportunity.

[9] Thanks to Texas Instruments for all the support.

[10] This work is dedicated to an incredible person that is not any more with us, **Laura Delgado Mata**, “*Rest peacefully*”.